NASA

4.0 Communication and Navigation Capability Roadmap

Executive Summary

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Overall Description

Capability Description

The space communication and navigation capability will fully enable evolution of the exploration and science programs. By providing connectivity to surface exploration and science vehicles and spacecraft, this capability ensures safe and productive mission operations. This capability is critical to eight other capabilities and moderate in relationship to the reminder.

The communications and navigation (C&N) capability is unique in that an architecture that defines it exists today to support current missions. The capability roadmap originates at this current state and evolves into the future. This evolution, required to meet the expanding needs of the exploration and science programs, involves the development of both architectures and enabling technology. The capability described in this report is based upon the current state of strategic roadmap development.

The C&N capability of the future, as pictured in Figure 1, is a highly adaptable network of networks that will rely on the modularity of relay satellite constellations, the flexibility of technology such as programmable communications systems, and an interoperable framework of spectrum, protocols and network architecture that will enable plug-and-play additions.

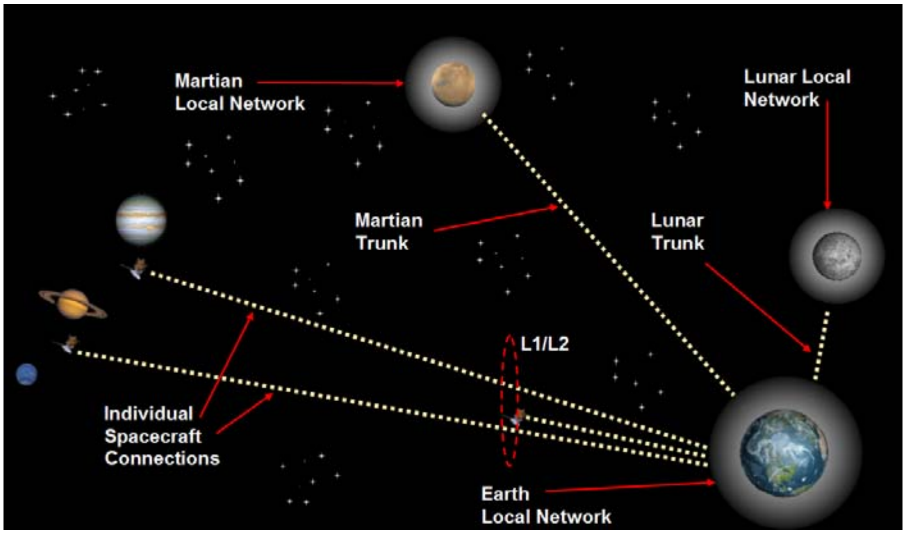

Figure 1 – Vision for the Communications and Navigation Architecture ~2030

Key features:

1. Sustainment and improvement of existing C&N capability of the Deep Space Network (DSN) and the Near-Earth Network (NEN) that includes the Earth-based relay satellite Space Network (SN) and the Ground Network (GN).
2. Establishment of a Lunar Relay satellite system to enable C&N capability on the Lunar far side and polar regions if required for data return to earth.

3. Establishment of a Martian Relay satellite system to enable C&N capability for robotic and human exploration.
4. Plug-and-play framework architecture enabling spacecraft level additions to the architecture and mission vehicles, both US and international.
5. Technology to accommodate anticipated higher data rates at farther distances from Earth (See Figure 2) and reduce user burden.

Note that detailed navigation architecture studies are underway and will be incorporated into the overall architecture and roadmap.

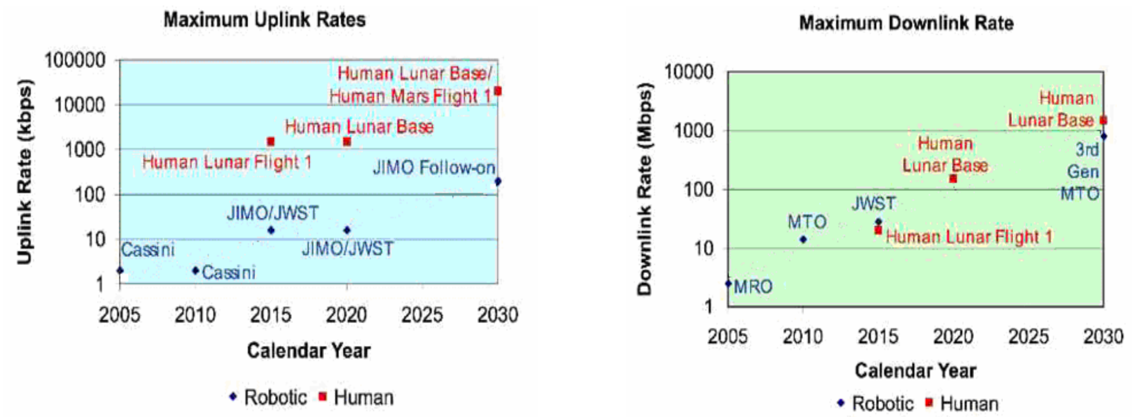

Figure 2 – Example Projection of Maximum Uplink and Downlink Rates (Mbps) for Human and Robotic Missions through 2030

Benefits

No mission can be executed without communications and navigation support:

- Safe flight requires adequate communications to address emergency and pending-emergency conditions.
- Full potential of investments in mission capability can only be realized with adequate communication for spacecraft and instrument control and data return
- Fulfillment of the exploration vision. As an example, current capabilities do not provide for humans exploring the far side of the moon or regions of the poles. The lunar network component of the C&N architecture must be developed to provide the necessary communication and navigation support to crew as well as robotics.
- Feedback to the owners and beneficiaries- the exploration vision cannot be fulfilled without the support of the public; the C&N architecture must provide the powerful link between the public and their exploration investment. This means that the architecture must evolve and adopt new technology in order to provide as much ‘virtual presence’ as possible, e.g. stereo HDTV, IMAX, control of robotics and instruments from publicly accessible locations such as universities, real-time comm with crew, ultra-high resolution photography of planetary surfaces and so on. (Figure 2)

The benefits of the C&N architecture include enabling increased crew and robotic productivity through collaborative operation with ground controllers, maintaining safe operations, providing precision navigation, and providing coverage during critical operations. Coverage of critical operations was identified as a key recommendation by the Mars Program Independent Assessment Team (MPIAT).

Key Architecture / Strategic Decisions

There are top level decisions that must be made on key requirements that drive the C&N architecture. These requirement drivers and their associated impact are listed in the table below.

	Key Architecture/Strategic Decisions	Date Decision is Needed	Impact of Decision on Capability
1.	Is coverage with communications connection needed for all critical maneuvers as required by Mars Program Independent Assessment Team Report (3/2000)?	2005	Determines critical decisions on TDRSS and Ka-Band antenna array needed to support Earth orbit of CEV and lunar backside burn.
2.	Is continuous available communications connection necessary for crewed vehicles?	2005	Determines critical decisions on TDRSS near earth network and lunar array needed to support Earth orbit of CEV and lunar backside burn.
3.	What will be the extent of development of Space Based Range as required by US Space Transportation Policy (12/2004)?	2005	Determines required decisions on TDRSS and near earth network needed to support Space Based Range capability.
4.	What is the location of human Lunar landing: far side limb area or potential interest area as referenced by The Vision for Space Exploration (2/2004)?	2012	Defines communications and navigation capability that may require a lunar relay system.
5.	Is connectivity during surface operations supporting over-the-horizon communications between individual units or crew members required.	2007 for lunar; 2012 for Mars	Lack of robust local network at lunar exploration site would constrain exploration operations. Lack of robust local network at Mars exploration site would constrain exploration operations.
6.	Is sufficient bandwidth available to meet increasing requirements contained within roadmaps; for example, lunar and Mars strategic roadmaps? Reference the President's Commission on Implementation of United States Space Exploration Policy (6/2004)	2010	Low data rates would constrain exploration activities at the moon and Mars.
7.	What are the precision landing and navigation requirements for Lunar and Mars missions?	2007 for lunar; 2012 for Mars	Appropriate navigation capability will not be in place to enable precision asset placement.

What are the major technical challenges?

The unifying challenge in the communications area is the need to move more data with higher quality, efficiency, flexibility, and interoperability than is currently possible. As shown in Figure 2, both science and public interest are increasing the demand for greater data rates, and as we explore at increasing distances new approaches and improvements in technologies are necessary.

Major Technical Challenges
2006-2010
Development of "Plug and Play" interoperable networks providing flexibility to allow international participation at the spacecraft level. • Issues: Spectrum, Protocols, Network Management & Services • Network of networks must be made adaptable through the use of programmable devices- • Ad-hoc network communication capabilities with end-to-end encryption and policy based architecture.
Development of Uplink Arraying Technology to enable ground antenna array to also transmit reducing costs for the replacement and maintenance of ground systems • Issues: alignment and tracking, measurement time-varying quantities, phasing, array elements distances • 2006 –Validate arraying concept using three 34-m DSN antennas using a moon bounce, LEOS experiment, and satellite experiments • 2010 – Initial evaluation of 12-m antenna array
2010 – 2020
Development of Optical Communication Capability (2018) for higher capacity communications at Mars and beyond with goal of 1 Gbps data rate at maximum Mars distance and on-station lifetime of 6 yrs). • Challenges for Ground-based detector (weather & turbulence) and space-based detector (array size, mass)
Develop Spacecraft RF Technology Capability with high availability, reliability and increased bandwidth. • Issues: space qualification of ground-proven 100kW Ka-Band TWTAs, and increase in operational reliability. Higher and more efficient Power Amplifiers: Traveling Wave Tube Amplifiers (TWTA) and Solid State Power Amplifiers (SSPA). • Deployment mechanisms and increasing operating frequency to Ka-band (Mesh and Inflatable Antennas)
Complete implemention of transmit operational capability to ground antenna array. • 2013 – Expanded 12-m array with operational status; off-ramp: build additional 34-m antennas • 2015 – If transmit array capability successful (see 2006-2010 above), then decommission the 34m antennas and cancel building 6 additional 34m antennas.
Develop Programmable Communication System Capability to provide flexible and adaptable communications systems with reduced mass, power, and weight. • Goal data rates in 2020- 25 Mbps for landers & 500 Mbps for orbiters/CEV, w/ required power of 1-25 W • Issues: reconfigurable logic, A/D converters, Memory, Hardware/Software (HW/SW) framework, common interfaces
Develop navigation capability for accurate positioning of spacecraft and landing support. • Issues : autonomous position determination and navigation support for Lunar far side and polar operations
2020 and Beyond
Develop higher capacity communications (Optical Communication) for more comprehensive Mars exploration • Data rate at maximum Mars distance is 2 Gbps with an on-station lifetime of 8 yrs
Develop Programmable Communication System to increase flexibility and adaptability with reduced mass, power, and weight.. • Data rates in 2030- 25-100 Mbps for landers & 1 Gbps for orbiters/CEV, w/ required power of 0.5 – 35 W • Issues: reconfigurable logic, A/D converters, Memory, HW/SW framework, common interfaces

<u>What are the key capabilities (enabling only) and what is their status?</u>

The following key capabilities were selected to reduce the cost of the communications systems while enabling a reasonable communications service level to meet currently understood mission objectives. The service level is based on assumed data rates, link availability and quality of service discussed elsewhere in this document. For example, the uplink arraying concept would significantly reduce the replacement, maintenance and operations costs for the DSN.

Key Capabilities and Status			
Capability/ Sub-Capability	**Mission or Roadmap Enabled**	**Current State of Practice**	**Minimum Estimated Development Time**
Lunar Relay Network	Lunar far side and polar operations	Near side Lunar operations using DSN antennas	5 Years
Mars Relay Network	Human Mars operations and continued/advanced Robotic operations	Mars Odyssey and Mars Global Surveyor spacecraft are used to relay data from the surface	Evolved over 15 Years
High Data Rate RF Technology (1 Gbps from Mars max distance)	High data rate from Mars, Solar System & Beyond	Example: Mars Global Surveyor 33 kbps, Mars Odyssey 14 kbps	10 Years
High Data Rate Optical Technology (1 Gbps from Mars max distance)	High data rate from Mars, Solar System & Beyond	None	4 Years (Demo 1 Mbps) 16 Years (Operational 1 Gbps)
Uplink Antenna Array -Initial 12-m Antenna Array and Extended	Deep Space, Mars, and Transit to both	Single dish antennas	5-8 Years
Downlink Antenna Array-Initial 12-m Antenna Array and Extended	Decommissioning of large DSN antennas	Single dish antennas	3 Years

Roadmap Development

Legacy Activities and Key Assumptions

Legacy Studies

NASA's Space Communications Architecture Working Group is charged with the task of developing an integrated space communications architecture, performing analyses, and making recommendations to NASA senior management. The working group has been active for over a year and includes representatives of the various line organizations, including science and future crewed exploration systems, the NASA Centers and the National Oceanographic and Atmospheric Administration. Also working group members interface with other government agencies. This working group continues to function and provided technical support to the Capability Roadmap Committee.

The BEACON study for a Unified Communications Architecture was aimed at producing a unified data services communication and navigation architecture. It included an assessment of requirements, architecture alternatives, operations concepts, and development of roadmaps that would provide the logical steps for implementation.

The Deep Space Mission System (DSMS) roadmap describes the future characteristics of deep space missions and how DSMS plans to meet the challenges that will arise. The roadmap provides guidance in the following areas: research and technology development across NASA mission offices that are involved with deep space exploration; major investment decisions that will be made over the next 25 years, and; mission designers as to new and enhanced capabilities of the DSN.

Roadmap Development Strategy

The development of the C&N capability hinges on a set of initial assumed requirements. These requirements will change as the exploration program matures. As a result the roadmap must accommodate decisions being built into the exploration plan, and the overall architecture approach must emphasize flexibility and evolvability to meet evolving needs and requirements. Initial focus has been on architecture and technology meeting near term budgetary action.

Assumed Top Level Requirements

The following assumptions were used in the development of this Roadmap:

- Space-based range - relay telemetry form launch vehicles, command destruct, and redundant telemetry paths
- Human space flight in LEO during Constellation Configuration - continuous communications with all vehicles and crew, coverage for multiple vehicles, comm services for configuration assembly, re-entry communications, comm for telemetry and crew voice on ocean surface
- Robotic missions to the far side of the Moon - comm during all critical events and systems out of view of Earth-based antennas

- Crewed lunar mission support - continuous comm for vehicles and crew, coverage over the back side of the Moon for critical events and human surface operations, voice and data services between elements over the poles, as well as to and from Earth
- Robotic missions to Mars - connectivity during critical events and to vehicles and probes on Mars surface
- Crewed Mars missions - continuous connectivity to support surface operations

Assumed Data Rates
Data rates will be major drivers for the C&N architecture as it evolves to meet the exploration and science mission needs. Currently, data rates are assumed based on assumed activities at various destinations in conjunction with characteristic data rates for typical data types. Example data types include High Definition Television (HDTV), Hyperspectral imaging, and audio. An example data rates scenario is shown in Figure 3. (NRT = near-real-time)

	User	Channel Content	Latency	# of Channels	Channel Rate	Total Rate
Operational	Base	Speech	NRT	2	10 kbps	20 kbps
		Engineering	NRT	1	100 kbps	100 kbps
	Astronauts	Speech	NRT	4	10 kbps	40 kbps
		Helmet camera	NRT	4	100 kbps	400 kbps
		Engineering	NRT	4	20 kbps	80 kbps
	Human Transports	Video	NRT	2	1.5 Mbps	3 Mbps
		Engineering	NRT	2	20 kbps	40 kbps
	Robotic Rovers	Video	NRT	8	1.5 Mbps	12 Mbps
		Engineering	NRT	8	20 kbps	160 kbps
	Science Orbiters	Quick Look	NRT	4	1 Mbps	4 Mbps
		Engineering	NRT	4	20 kbps	80 kbps
High Rate	Base	HDTV	1 day	1	20 Mbps	20 Mbps
	Human Transports	HDTV (Medical and PIO)	NRT	2	20 Mbps	40 Mbps
		Hyperspectral Imaging	1 day	1	150 Mbps	150 Mbps
	Robotic Rovers	Surface Radar	1 day	1	100 Mbps	100 Mbps
		Hyperspectral Imaging	1 day	1	150 Mbps	150 Mbps
	Science Orbiters	Orbiting Radar	1 day	2	100 Mbps	200 Mbps
		Hyperspectral Imaging	1 day	2	150 Mbps	300 Mbps
	Total					980 Mbps

Figure 3 – Assumed Data Rates Scenario

C&N Capability Breakdown Structure Rationale [Figure 4]

The Capability Breakdown Structure (CBS) in Figure 4 is indicative of one of the central issues of the C&N architecture: the C&N capability is really a set of services that are provided to users in various locations. By nature, the way in which a service is provided, or the difficulty in achieving service performance, is tied to the phase of flight or location. For this reason, the first level of capability breakdown represents providing C&N service during launch, Earth orbit, transit (to Moon, Mars, or beyond), Lunar operations, Mars operations, and exploration in the Solar System & Beyond. The sub capabilities then reflect the specific services needed in each regime.

C&N Roadmap Description [Figure 5, Figure 6]

The C&N roadmap is described in two segments, 2005-2020 (Figure 5) and 2020-2035 (Figure 6). The key exploration assumptions on the uppermost portion of the roadmap provide a context for the C&N architecture development by indicating the missions and activities that will be supported. The C&N milestones consist of architecture implementations ranging from initial relay constellations at the moon, to 12-m antenna arrays at Earth capable of transmitting. Listed below are some of the key communications architecture decisions that must be addressed.

	Key Architecture/ Strategic Decisions[¥]	Date Decision is Needed	Impact of Decision on Capability (capability development required by the decision)
	Technology Support Level of Effort	2005	Critical technology investments must be made in order to ensure progress of the overall architecture evolution.
	LRO and RLEP Lunar Relay Communications Capability	2005	Enables RLEP series missions to land robotic vehicles on the backside of the Moon by providing communication relay links to backside surface locations that are out of line of sight of Earth antennas
	Initial Antenna Array Increment	2005	Provides start on long term scalable antenna architecture that will lead to replacement of large DSN antennas
	Tracking and Data Relay Satellite System Continuation (TDRSS-C)	2005	Provides for continuity of current TDRSS capability providing continuous connections for human spacecraft and coverage for critical events for robotic spacecraft in LEO (i.e. Constellation assembly)
	Transmit Antenna Array Technology Development	2006	Key to acquisition decision in ~ 2012 time frame on decommissioning 34m DSN antennas
*	Human & Robotic Support - Lunar Communication Relay: Pre-Acquisition	2007	Enables human missions / base on Lunar backside in ~ 2017 time frame. (If pre-acquisition work is not done prior to 2010, 2017 milestone will not be met. Current SCAWG cost model assumes that pre-acquisition work begins in 2007 to support a 2017 IOC.)
*	Human & Robotic Support -Lunar Communication Relay: Acquisition	2010	Decision to proceed with development of lunar relay necessary to support human base on lunar back side in the 2017 timeframe
	Implementation of Space-based Deep Space Optical Receivers	2010	Opportunity to include Deep Space Optical Communication receivers on TDRS-C to provide capability for MTO-2 and beyond (pre-acquisition studies must occur before 2010)
* *	Space-based Range Requirements	2010	Must incorporate changes into TDRSS-C (pre-acquisition studies must occur before 2010)
* *	Upgrade Optical Comm on MTO2	2011	MTO2 “scheduled” for 2015
	Transmit Antenna Array	~ 2012	Enables decommission of 34m DSN antennas in 2015
* *	Mars Optical Comm Operational	2015	2nd generation MTO ~2020 will require 5 year lead for development

¥ Prerequisite to comm/nav architecture and capability is knowledge of the mission set and scenarios that describe the users and requirements
**Issue: decision to support lunar comm relay for backside and poles (2010) is needed prior to the expected decision date for exploration location based on early robotic mission results (2012, per SRM)*
*** Space-based range, MTO2, and 2nd Generation MTO are not included in the SRM strategic milestones*

The sub-capabilities, as noted earlier, represent regimes in which C&N services must be provided. The markers in this section denote technology capabilities or architecture implementations that support C&N evolution in these various regimes. As an example, in 2006, an initial uplink array capability will be possible using three 34-m antennas. Uplink arraying will be applicable for missions in transit to Mars or places in the Solar System & Beyond, hence the three markers in those regimes. An additional example: programmable communications systems will be capable of providing 100 Mbps in the 2020 timeframe, and is marked under Lunar, Mars, and Solar System & Beyond, indicating its wide applicability and criticality.

Assessment of the current state of the art of the overall roadmap capabilities

Current State of Practice of C&N Capabilities			
Capability/ Sub-Capability	**Mission or Roadmap Enabled**	**Current State of Practice**	**Minimum Estimated Development Time**
Earth Relay Continuation	Earth orbiting missions, missions requiring launch / reentry support	Tracking and Data Relay Satellite System (TDRSS) geostationary satellites provide coverage currently. Global coverage is dependent on the replacement of these relays as they reach the end of their design life.	8 Years
Space Based Range	High data rate and/or redundant coverage of launch and early orbit for all missions	Low rate telemetry and command support from launch head ground stations and TDRS	5 Years
Optical Comm Demonstration from Mars (1 Mbps)	High data rate return from Mars	RF communications only – kbps	In development for 2009 Launch
Programmable Communications Technology	Missions in transit, at Mars, and throughout the Solar System & Beyond	Current technology supports lesser data rates at an increased mass and power burden	5 Years for 10Mbps-level capability, 15 Years for 100 Mbps-level capability, 25 Years for 1 Gbps-level capability
Spectrum Interoperability	All co-located missions where data transfer can be routed through an alternate spacecraft	Planned interoperability for proximity communications at Mars: Example is MER data transfer through an ESA orbiter	Spectrum Agreements via the Space Frequency Coordination Group and the World Radio Council between 2005 and 2010
Communication Protocols Standardized			6 Years via CCSDS Development
Network Architecture and Management	All Missions		2005-2010

Relationship to Other Capability Roadmaps

The C&N capability roadmap has critical relationships with eight of the other capability areas. Details on the nature of those critical relationships follow.

In Space Transportation

- Requires Tracking Telemetry and Control (TT&C) link to Earth
- Key dependence on TT&C during critical event coverage
- Vehicle-to-Vehicle links needed for assembly and docking operations
- Communications security needed
- Navigation requirement is continuous
- Navigation provided by combination of autonomous and linked methods
- Requires time phasing of capability with missions

Advanced Telescopes and Observatories

- Critical dependence on TT&C and mission data transport links to Earth (or Earth orbiting relay)
- Potential TT&C and mission data transport links to lunar or planetary orbiter
- Comm security needed
- Dependence on navigation critical for formation flying, VLBI, or scientific instrument pointing
- Navigation provided by combination of autonomous and linked methods
- May have crosslinks between array elements

Robotic Access to Planetary Surfaces

- Dependent on TT&C and mission data transport links to Earth, Earth orbiter, or lunar or planetary orbiter
- May require surface-to-surface links or network
- Comm security needed
- Navigation provided by combination of autonomous and linked methods
- Requires time phasing of capability with missions

Human Planetary Landing Systems

- Critical dependence on assured TT&C, voice, and mission data transport links to Earth, Earth orbiter, or lunar or planetary orbiter
- May require surface to lander beacon link
- May require surface-to-surface links or network
- Comm security needed
- Critical dependence on highly reliable, highly available navigation
- Navigation provided by combination of autonomous and linked methods
- Navigation and communication required for rendezvous and docking
- May incorporate docking sensor on vehicle
- Requires time phasing of capability with missions

Human Exploration Systems and Mobility

- Critical dependence on assured TT&C, voice, and mission data transport links to Earth, Earth orbiter, or lunar or planetary orbiter
- Astronaut EVA suits may require TT&C, voice and mission data links
- May require surface-to-surface links or network
- Comm security needed
- Potential mission data dependence on in-space deployable antennas
- Critical dependence on highly reliable, highly available navigation
- Navigation provided by combination of autonomous and linked methods
- Requires time phasing of capability with missions

Autonomous Systems and Robotics

- Critical dependence on system-to-system autonomous communication network for TT&C and mission data transport with systems located nearly anywhere
- May require links for critical event coverage
- May require communication on demand networking
- May require inter-vehicle communication for rendezvous / docking
- Navigation provided by combination of autonomous and linked methods

Transformational Spaceport/Range

- Critical dependence on assured TT&C, voice, and mission data transport links to Earth or Earth orbiter
- Critical dependence on highly reliable, highly available navigation
- Tradeoff of range radar or space-based range (SBR increases dependence on comm/nav and GPS)
- Range radar can provide autonomous tracking w/out dependence on vehicle TT&C
- Comm security needed
- Navigation provided by combination of autonomous and linked methods
- Requires time phasing of capability with missions

Scientific Instruments and Sensors

- Critical dependence on TT&C and mission data transport links to Earth (or Earth orbiting relay)
- Potential TT&C and mission data transport links to lunar or planetary orbiter
- Comm security needed
- May have crosslinks between array elements
- May require inter-instrument communications
- Requires time phasing of capability with missions

<u>Identification of key national expertise/assets/facilities, that are needed for the capability</u>

Facilities and people are extremely important for the Communications and Navigation capability. While not exhaustive this listing indicates the breadth and depth of facilities and competencies that are needed for the Communications and Navigation capabilities.

Facilities and Assets:

- Deep Space Network ground stations at Canberra, Goldstone, Madrid
- Ground stations including White Sands Complex, MILA, KSC, WFF, GRGT
- Research and test facilities at JPL, GSFC, and GRC
- Tracking and Data Relay Satellite System (TDRSS)

Critical workforce competencies:

- RF and Optical communications technologists
- NASA: GSFC, JPL, GRC, JSC, KSC, and associated contractors
- Laboratories: MIT Lincoln Labs, JHU Applied Physics Lab, Naval Research Lab, Sandia National Lab, Air Force Research Lab
- Universities

Human capital considerations:

- Critical competencies must be maintained
- Improved workforce competency in new and emerging technology areas such as optical communications and programmable communication systems

To be successful these assets must be carefully managed.

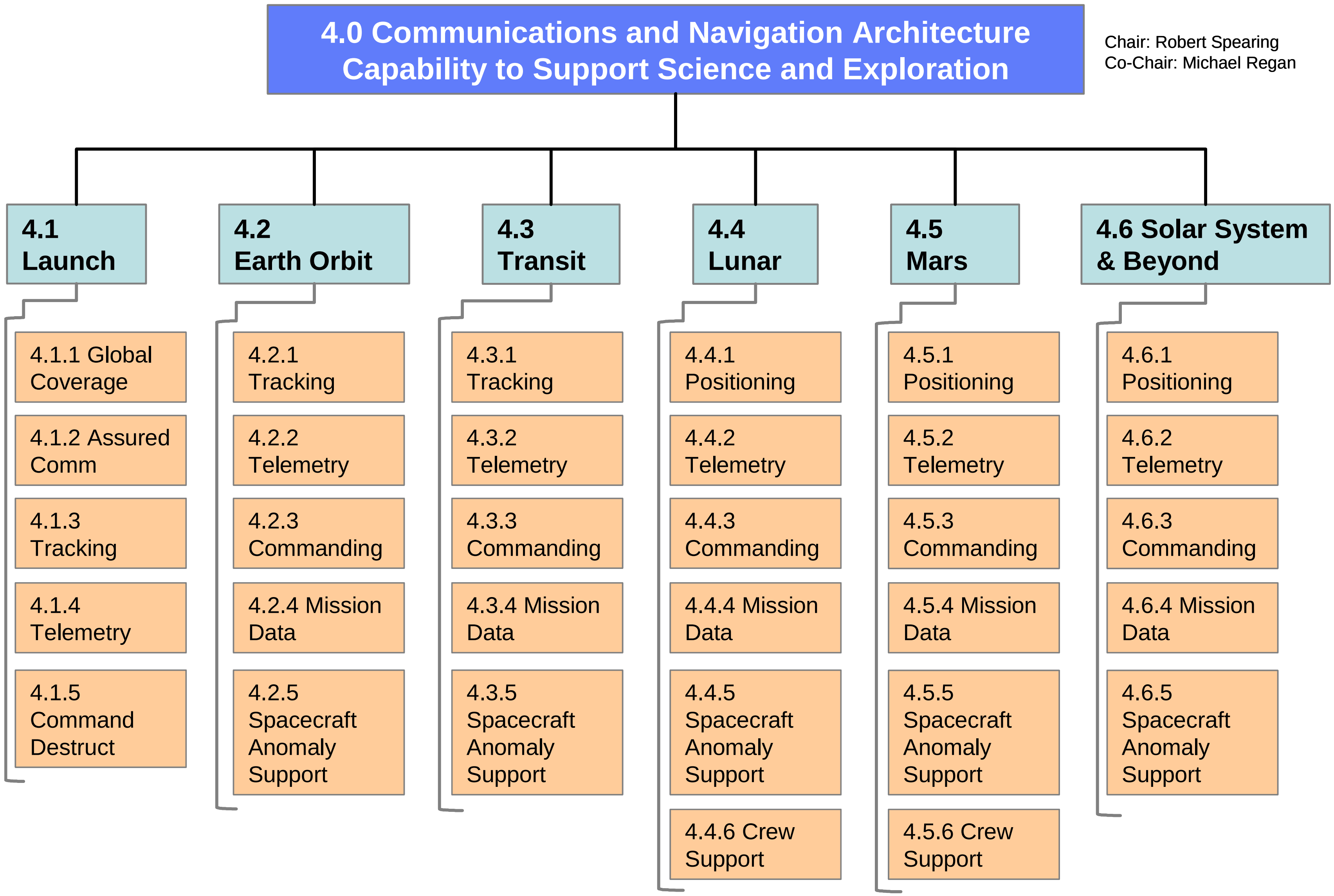

Figure 4 – C&N Capabilities Breakdown Structure (CBS)

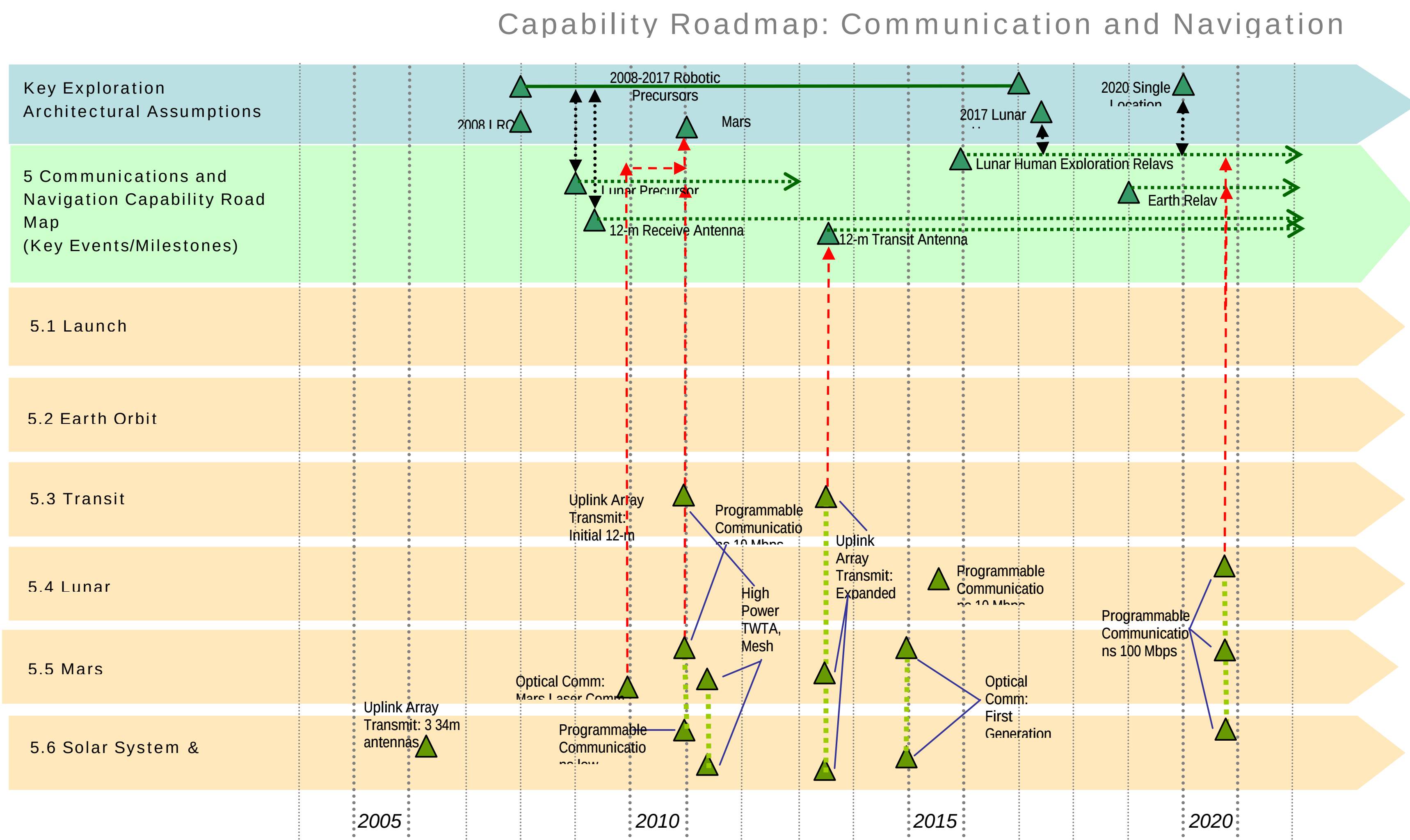

Figure 5- Top Level Exploration Capability Roadmap Rollup (2005-2020)

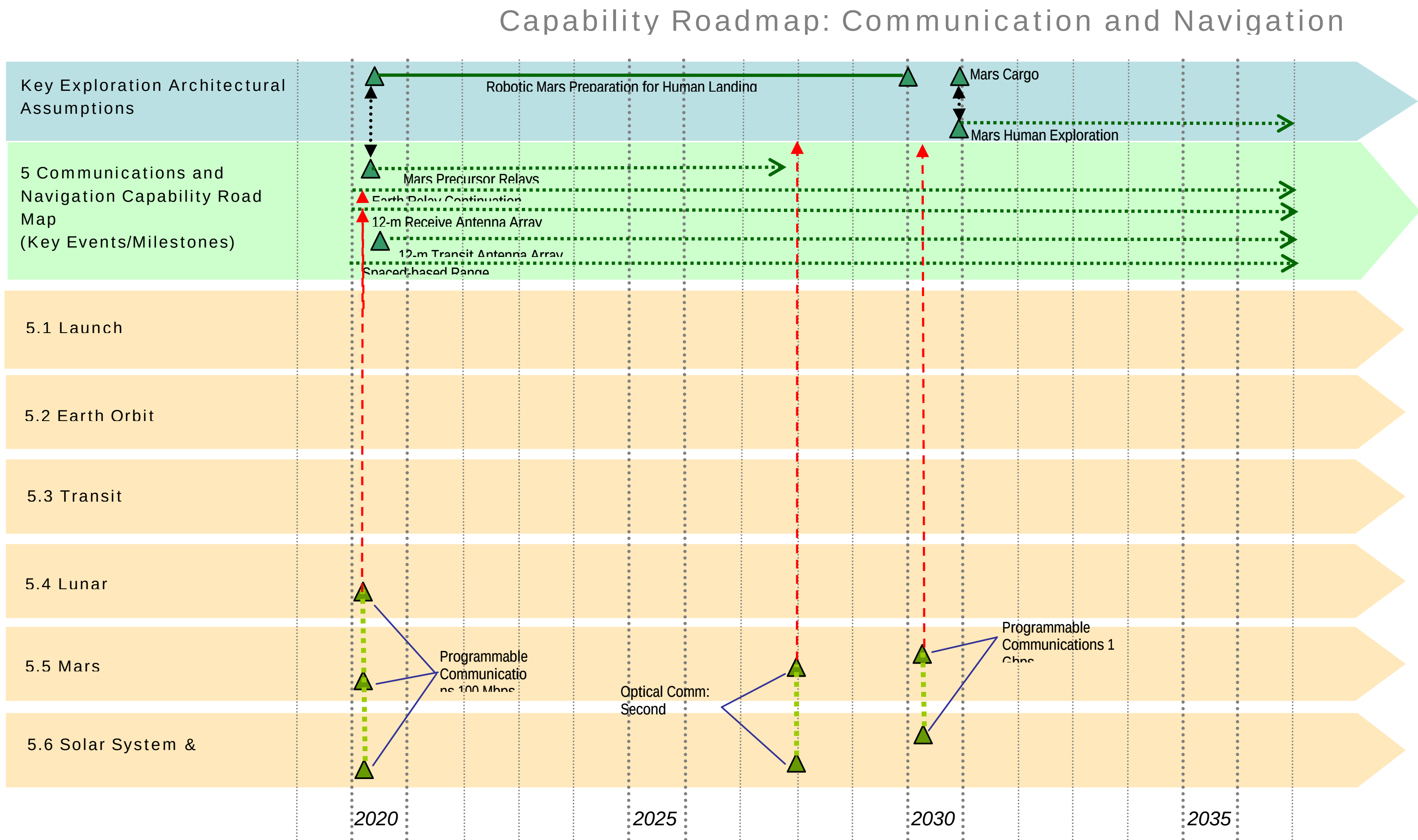

Figure 6 - Top Level Exploration Capability Roadmap Rollup (2020-2035)

Summary

The C&N Capabilities Roadmap process has identified the need for a robust, evolvable, scalable, and adaptable communications and navigation architecture. This capability is essential for the success of exploration and science missions and is either critical or moderate in relationship to the other 14 capabilities. The top-level vision for the C&N architecture consists of a network of networks based on the use of relay satellites at Earth, Moon, and Mars and replacement of the DSN antennas with scalable, small aperture antenna array technology. Key enabling technologies have been identified to ensure the success of this vision: optical communication, spacecraft RF technology, antenna array transmit technology and programmable communication systems. This initial roadmap was developed as a result of exploration and science inputs and assumptions to date, and architecture and technology analysis. Continuation of this work will include further assessment of enabling technology, network level management and protocols, and updating and validation of assumed driving requirements. In addition, the architecture will fully address the navigation aspects.

Acronym List

A/D – Analog/Digital
AFSCN – Air Force Satellite Control Network
ARC – Ames Research Center
BW – Bandwidth
C&N - Communications and Navigation
CCSDS — Consultative Committee for Space Data Systems
CEV – Crew Exploration Vehicle
CM – Command Module
COMM – Communications
DSN – Deep Space Network
ESA – European Space Agency
FCC – Federal Communications Commission
FF – Fast Forward
FOM – Figure of Merit
FOM — Figures of Merit
FWD – Forward Link
Gbps – Gigabits per second
GDOP – Geodetic Dilution of Precision
GEO – Geosynchronous Earth Orbit
GN – Ground Network
GPS – Global Positioning System
GRC – Glenn Research Center
GRGT – Guam Remote Ground Terminal
GSFC – Goddard Space Flight Center
GT – Ground Terminal
HDTV – High Definition Television
HPOA – High Power Optical Amplifier
ISO – International Standards Organization
ISS — International Space Station
JIMO – Jupiter Icy Moons Orbiter
JPL – Jet Propulsion Laboratory
JTR – Joint Tactical Radio
KSC – Kennedy Space Center
KuSA – Ku-Band Single Access
L&EO – Launch and Early Orbit
L1 – LaGrange Point 1
L2 – LaGrange Point 2
LaRC – Langley Research Center
LEO – Low Earth Orbit
LLO – Low Lunar Orbit
LMO – Low Moon Orbiter
LOS – Line of Sight
LRO – Lunar Reconnaissance Orbiter
Mbps – Megabits per second

MCC – Mission Control Center
MLCD – Mars Lasercom Demonstrator
MOC – Mission Operations Center
MTO – Mars Telecom Orbiter
NAFCOM – NASA Air Force Cost Model
Nav – Navigation
NISN – NASA Information System Network
NRT – Near Real Time
NSF – National Science Foundation
OC – Operations Center
OPS – Operations
PDD – Presidential Decision Directive
PIO – Public Information Office
R&D - Research and Development
RE – Recurring Engineering
RF – Radio Frequency
RLEP – Robotic Lunar Exploration Program
RS – Relay Satellite
SA – Single Access
SC – Spacecraft
SDR – Software Defined Radio
SFCG – Space Frequency Coordination Group
SGL – Space Ground Link
SLE – Space Link Extension
SN – Space Network
STS – Space Transportation System
TDRSS — Tracking Data Relay Satellite System
TT&C – Tracking, Telemetry and Command
TWTA – Traveling Wave Tube Amplifier
UHF – Ultra High Frequency
UMD – University of Maryland at College Park
USG – United States Government
WRC – World Radio Conference
WSC – White Sands Complex